APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

METHOD OF INTERPOLATING COLOR PIXEL SIGNALS
FROM A SUBSAMPLED COLOR IMAGE

Inventor(s): Tinku Acharya
Ajay K. Ray
A.K.V. Subba Rao

Prepared by: Howard Skaist,
Senior IP Attorney

intel®
Intel Corporation
2111 N. E. 25th Avenue; JF3-147
Hillsboro, OR 97124
Phone: (503) 264-0967
Facsimile: (503) 264-1729

"Express Mail" label number EL414968736US

METHOD OF INTERPOLATING COLOR PIXEL SIGNALS FROM A SUBSAMPLE COLOR IMAGE

BACKGROUND

Field

This disclosure is related to interpolating pixel signal values for an image and, in particular, interpolating color pixel signal values from a subsampled color image.

Background Information

As is well-known, in a variety of circumstances, it is desirable to perform color interpolation. For example, for a camera or other imager that has the capability of creating a color image, typically it is too expensive to have the capability to capture three independent color pixel signal values for each pixel location of an image. Therefore, more typically, a subsampled color image is captured and then the missing color pixel signal values are computed using techniques of color interpolation. Most of the existing simple color interpolation techniques typically do not produce high-quality color images. Therefore, a need continues to exist for color interpolation capable of producing quality color images from a subsampled color image.

SUMMARY

Briefly, in accordance with one embodiment of the invention, a method of interpolating color

pixel signals from a subsampled color image includes the following. For a particular pixel location in a subsampled color image, relative changes in a particular color pixel signal value are compared for two mutually orthogonal directions across the particular pixel location using pixel signal values immediately adjacent to the particular pixel location. A color signal value for that particular pixel location for a color plane other than the color plane of the pixel signal value in the subsampled color image of that location is computed by relatively weigh the pixel signal values, the relative weights depending, at least in part, on the relative change of pixel signal value level in a particular direction.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

FIG. 1 is a schematic diagram illustrating a subsampled color image, such as a Bayer pattern color mage;

FIG. 2 is a schematic diagram illustrating a portion of a subsampled color image in which the color pixel signal values are to be employed by an embodiment of a method in accordance with the present invention;

FIG. 3 is a schematic diagram illustrating a portion of a subsampled color image in which the

color pixel signal values are to be employed by an embodiment of a method in accordance with the present invention;

FIG. 4 is a schematic diagram illustrating a portion of a subsampled color image in which the color pixel signal values are to be employed by an embodiment of a method in accordance with the present invention.

DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

As previously indicated, in a variety of circumstances it may be desirable to have a capability to interpolate color pixel signals from a subsampled color image in order to recover the missing color components in a particular pixel location. Fig. 1 is a schematic diagram illustrating a Bayer pattern color image, which is one example of a subsampled color image, although the invention is not limited in scope in this respect. For example, many other well-known subsampled color images may be employed as will provide satisfactory results. As previously indicated, unfortunately, many color interpolation techniques typically do not produce high-quality color images because the techniques

employed typically do not take into account, or at least reasonably correctly take into account, how the human eye perceives color. For example, a typical color interpolation technique may include averaging the pixels adjacent to a particular pixel location in which it was desired to interpolate the color signal value for those colors not included in that pixel location of a subsampled color image. However, typically, simply employing a pure average does not produce high quality results because it blurs the edge information and produces color aliasing problem, for example.

In this particular embodiment of a method of interpolating color pixel signals from a subsampled color image in accordance with the present invention, the color interpolation is accomplished by comparing relative changes in mutually orthogonal directions across the particular pixel location using pixel signal values immediately adjacent to that particular pixel location. It is assumed that if a significant change in a particular color pixel signal value occurs, that change is not as representative of the signal values at the particular pixel location as are the signal values from the mutually orthogonal direction. For example, it may be that in the image, an edge is being encountered. Therefore, in computing the color signal value for that particular pixel location, a direction that indicates less change in signal value is weighed more heavily, in this particular embodiment. It is believed that this is more representative of how the human eye perceives color because the human vision system is more responsive to the relative change of color in the neighboring pixels than to the color information in the pixel itself. In addition, as explained in more detail hereinafter, in computing some pixel signal

values for particular colors, natural logarithms are employed because it is believed that natural logarithms capture how the human eye perceives relative color.

Fig. 2 is schematic diagram illustrating a three pixel-by-three pixel portion of the Bayer pattern of Fig. 1. As illustrated, the center pixel location comprises a red pixel signal value. Therefore, for this particular pixel location, it is desired to interpolate the missing color signal values, blue and green, for that pixel location from the surrounding pixel signal values. For example, a green pixel signal value may be estimated as follows. As illustrated in Fig. 1, the immediately adjacent pixel locations in the horizontal and vertical directions comprise green pixel signal values. Therefore, these shall be employed to estimate the green pixel signal value for this particular pixel location. First, the relative change in the green pixel signal values for the horizontal direction and the vertical direction across this particular pixel location is computed and compared. This is accomplished using the following equations.

$$\text{Chor} = G_{m,n+1} - G_{m,n-1};$$
$$\text{Cver} = G_{m+1,n} - G_{m-1,n};$$

If the relative change in the vertical direction is greater than the relative change in the horizontal direction, the relative change being relative to the magnitude of the values computed above, then the values in the horizontal direction, that is, in this embodiment, the green pixel signal values that are the immediately adjacent pixel signal values in the horizontal direction, are weighed more heavily. In

this embodiment, the weight assigned to horizontal green pixel values have been chosen, based on experimentation, as 0.5, although the invention is not limited in scope in this respect. It is noted that other weights may be employed and provide satisfactory results. At the same time the weights assigned to vertical neighboring green pixel signal values have been chosen as 0.1, although the invention is not limited in scope in this respect.On the basis of the above discussion the missing green pixel signal values in this particular pixel location is estimated as

$$G_{m,n} = [\ 0.5 * (G_{m,n-1} + G_{m,n+1}) + 0.1 * (G_{m-1,n} + G_{m+1,n})\ ] / (0.5 + 0.5 + 0.1 + 0.1); \text{ or}$$

$$G_{m,n} = 0.41667 * (G_{m,n-1} + G_{m,n+1}) + 0.08333 * (G_{m-1,n} + G_{m+1,n});$$

However, if the relative change in the horizontal direction is greater than the relative change in the vertical direction, in terms of pixel signal level for the green pixel signal values, then a reverse approach is employed. More particularly, the vertical green pixel signal values that are immediately adjacent to the red pixel signal value, in this particular embodiment, are weighed more heavily. In particular, the green pixel signal value in this particular pixel signal location is estimated as follows.

$$G_{m,n} = 0.08333 * (G_{m,n-1} + G_{m,n+1}) + 0.41667 * (G_{m-1,n} + G_{m+1,n});$$

It is noted that the form of this equation is similar to the form above, except that the vertical and horizontal pixel signal values that are immediately adjacent to the red pixel signal value have been interchanged. Finally, if the two relative changes are equal, or substantially equal, then a simple average of the four green pixel signal values that are immediately adjacent to the red pixel signal

value are averaged, for this embodiment, in accordance with the following equation.

$$G_{m,n} = 0.25 * (G_{m,n-1} + G_{m,n+1} + G_{m-1,n} + G_{m+1,n});$$

Therefore, in order to compute the signal value for the green color plane, where the particular pixel location has a pixel signal value in the red color plane, the pixel signal values immediately adjacent to that pixel location in the green color plane are compared. As shall be described in more detail below, it is not always the case that the color plane being computed corresponds to the particular color of the pixel signal values that are compared, although it is true in this embodiment for the situation just described.

It is noted that where the particular pixel location has a blue pixel signal value in the Bayer pattern shown in Fig. 1, the structure of a three pixel-by-three pixel portion of the sub-sampled color image is similar in arrangement to that illustrated in Fig. 2, except the center pixel contains the blue information instead of red. Therefore, for a pixel location containing the blue signal value, the missing green pixel signal value for that pixel location may be estimated by using the same technique previously described.

Fig. 3 is schematic diagram of another portion of the Bayer pattern of Fig. 1. This three pixel-by-three pixel portion is essentially the same as that shown in Fig. 2, except that pixel signal values in the respective corners of the three-by-three array have also been provided. For this portion, it is

desirable to interpolate a blue pixel signal value for the location in which a red pixel signal value is provided. However, as illustrated in Fig. 3, blue pixel signal values immediately adjacent to the red pixel signal value are provided in the corners. Therefore, in contrast with the approach just described, the two mutually orthogonal directions to be compared comprise the main diagonal and the secondary diagonal of the array of pixels. However, instead of comparing the relative change in pixel signal value level for the blue pixel signal values directly, the relative change in hue across these two diagonals shall be compared. Hue, in this context, for red and blue, refers to the relative signal value of a blue or red pixel signal value to a green pixel signal value. The reason this approach is employed is because it is believed that hue information more accurately reflects how the human eye perceives changes in color. Furthermore, a comparison for red and blue pixel signal values is made with green pixel signal values because, in RGB color space format, the green plane includes a relatively larger amount of luminosity signal information compared to the red and blue and hue of the red or the blue is estimated by comparing with the green value. Therefore, hue for the four blue pixel signal values is computed by comparing the blue pixel signal value in that location with the green pixel signal value in that location. It should be noted that the missing green pixel value has already been recovered via the previous technique. Therefore, the following equations apply.

$$hue\_nw = B_{m-1,n-1} - G_{m-1,n-1};$$

$$hue\_sw = B_{m+1,n-1} - G_{m+1,n-1};$$

$$hue\_ne = B_{m-1,n+1} - G_{m-1,n+1};$$

$$hue\_se = B_{m+1,n+1} - G_{m+1,n+1};$$

Then, the hue along the main diagonal and the secondary diagonal are computed as follows.

$$hue\_md = hue\_nw - hue\_se;$$

$$hue\_sd = hue\_ne - hue\_sw;$$

As discussed above, if the hue in any particular direction changes more significantly, then the hue in the orthogonal direction is employed to estimate the blue pixel signal value in a particular pixel location. More accurately, the hue in that direction in which there is less change in hue is weighed more heavily than in the direction in which change in hue is more .This strategy is employed to estimate the hue in that particular pixel location. However, from the hue, the blue pixel signal value may be estimated as follows.

$$\log(B_{m,n}) = \log(G_{m,n}) + 0.41667 * (\log(B_{m-1,n-1}/ G_{m-1,n-1}) + \log(B_{m+1,n+1}/ G_{m+1,n+1})) + 0.08333 * (\log(B_{m-1,n+1}/ G_{m-1,n+1}) + \log(B_{m+1,n-1}/ G_{m+1,n-1}));$$

Likewise, a similar equation is employed for the opposing diagonal, except that the signal values along the diagonals are interchanged, providing the following equation.

$$\log(B_{m,n}) = \log(G_{m,n}) + 0.08333 * (\log(B_{m-1,n-1}/ G_{m-1,n-1}) + \log(B_{m+1,n+1}/ G_{m+1,n+1})) + 0.41667 * (\log(B_{m-1,n+1}/ G_{m-1,n+1}) + \log(B_{m+1,n-1}/ G_{m+1,n-1}))$$

Likewise, as mentioned previously, the natural logarithm is employed in this particular embodiment because it is believed that it reflects or captures how the human eye perceives relative

color. It is noted that interpolation of a red pixel signal value for a particular pixel location having a blue pixel signal value may be obtained using a similar approach except that in the above equation the blue pixel signal values are interchanged with red pixel signal values. This is because, as illustrated in Fig. 1, where the particular pixel location has a blue pixel signal value, the pixel signal values in the four corners are red pixel signal values, therefore, providing the same structure or array layout as illustrated in Fig. 3.

Finally, a blue pixel signal value may be interpolated where a green pixel signal value is provided in the particular pixel location of the subsampled image, as illustrated in Fig. 4, for example. The approach is similar to that described in connection to that described with Fig. 3, except that, instead of employing the pixel signal values along the diagonals, the horizontal and vertical pixel signal values are employed using either horizontal or vertical pixel signal value directly available from the subsampled color image. The other pixel value in the orthogonal direction which is used for interpolation is obtained by employing the previous technique. Likewise, the blue pixel signal values in the horizontal locations immediately adjacent the green pixel signal values in Fig. 4 are interpolated using the approach just described above in connection with Fig. 3. Therefore, the following equations are employed.

$$hue\_n = B_{m-1,n} - G_{m-1,n} \cdot$$

hue_e $= B_{m,n+1} - G_{m,n+1}$.

hue_w $= B_{m,n-1} - G_{m,n-1}$.

hue_s $= B_{m+1,n} - G_{m+1,n}$.

hhor $=$ hue_e $-$ hue_w.

hver $=$ hue_n $-$ hue_s.

if (| hhor| < |hver|) ***then***

$$\log(B_{m,n}) = \log(G_{m,n}) + 0.41667 * (\log(B_{m,n-1}/ G_{m,n-1}) + \log(B_{m,n+1}/ G_{m,n+1})) + 0.08333 * (\log(B_{m-1,n}/ G_{m-1,n}) + \log(B_{m+1,n}/ G_{m+1,n})).$$

else

$$\log(B_{m,n}) = \log(G_{m,n}) + 0.08333 * (\log(B_{m,n-1}/ G_{m,n-1}) + \log(B_{m,n+1}/ G_{m,n+1})) + 0.41667 * (\log(B_{m-1,n}/ G_{m-1,n}) + \log(B_{m+1,n}/ G_{m+1,n}))$$

endif

A similar approach may be employed to interpolate the red pixel signal value where the particular pixel location of the subsampled image includes a green pixel signal value, except that in the equations provided above, the blue pixel signal values are replaced by red pixel signal values, as follows

hue_n $= R_{m-1,n} - G_{m-1,n}$.

hue_e $= R_{m,n+1} - G_{m,n+1}$.

hue_w $= R_{m,n-1} - G_{m,n-1}$.

hue_s $= R_{m+1,n} - G_{m+1,n}$.

hhor = hue_e - hue_w.

hver = hue_n - hue_s.

if (| hhor| < |hver|) ***then***

$$\log(R_{m,n}) = \log(G_{m,n}) + 0.41667 * (\log(R_{m,n-1}/ G_{m,n-1}) + \log(R_{m,n+1}/ G_{m,n+1})) + 0.08333 * (\log(R_{m-1,n}/ G_{m-1,n}) + \log(R_{m+1,n}/ G_{m+1,n})).$$

else

$$\log(R_{m,n}) = \log(G_{m,n}) + 0.08333 * (\log(R_{m,n-1}/ G_{m,n-1}) + \log(R_{m,n+1}/ G_{m,n+1})) + 0.41667 * (\log(R_{m-1,n}/ G_{m-1,n}) + \log(R_{m+1,n}/ G_{m+1,n}))$$

endif

It will, of course, be appreciated that the invention is not restricted in scope to a particular embodiment or implementation. For example, the foregoing approach, as one example of an approach in accordance with the invention, may be implemented in hardware, in software, in firmware, and any combination thereof. Again, intended merely as examples that do not limit the scope of the invention, an embodiment may comprise an imager including hardware, such as integrated circuit chips, that implement the foregoing. Alternatively, the imager may be coupled to a computing platform that includes software capable of implementing the foregoing. Likewise, a digital camera coupled to a desktop personal computer, for example, may implement an embodiment. Furthermore, these implementations in hardware and software may, of course, deviate from the foregoing and still be within the scope of the present invention.

For embodiments that are at least partially implemented in software, such as, for example, the previously described embodiment, such software may reside on a storage medium, such as, for example, random access memory, a CD ROM, a floppy disk, or a hard drive, such that instructions are stored, which, when executed, such as by a computing platform, such as a PC or other computing device, the system is capable of executing the instructions to result in the interpolation of color pixel signal values from a subsampled image. Likewise, such software may reside in firmware also, such as in flash memory or EEPROM, for example.

While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.